The Status of CO$_2$ EOR in Texas

CO$_2$ for EOR as CCUS:
A Collaborative Symposium on CO$_2$ EOR
Rice University
November 19, 2013
THE PHASES OF CO₂ ENHANCED OIL RECOVERY
as Referenced to the Permian Basin Region of the U.S.

PERMIAN BASIN CO₂ PROJECT STARTS

YEARLY PROJECT STARTS


YEAR

CUM PROJECT STARTS
Current Situation – CO₂ EOR Projects

GROWTH OF WW, U.S. and PERMIAN BASIN CO₂ EOR PROJECTS 1992 - 2012

- Worldwide Projects
- U.S. Projects
- Permian Basin Projects

YEARS:
- 1992
- 1994
- 1996
- 1998
- 2000
- 2002
- 2004
- 2006
- 2008
- 2010
- 2012

NO. OF PROJECTS:
- 0
- 20
- 40
- 60
- 80
- 100
- 120
- 140
- 160
Current Situation – CO₂ EOR Production

WW, U.S., & PB CO₂ EOR PRODUCTION
1986 - 2012

- Worldwide
- U.S.
- Permian Basin

YEAR

CO₂ EOR PRODUCTION - kbopd

* Ref: O&GJ Biennial EOR Editions & UTPB Petr Industry Alliance

Modified from Murrell, 2012, Melzer 2012, 6th Wy Annual CO2 Conf;
Historical CO₂ Sales: U.S. and Permian Basin

- CO₂ Average Daily Sales in mmcfpd

- Year

- Permian Basin
- North Amer

PB Dominated  →  Changing World
## New Texas CO₂ Floods

<table>
<thead>
<tr>
<th>Field/Unit</th>
<th>Operator</th>
<th>CO₂ Vols (mmcfpd)</th>
<th>EOR Vols (bopd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Perryton</td>
<td>Chaparral Energy</td>
<td>20</td>
<td>2500</td>
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<td>Albert Spicer Unit</td>
<td>Chaparral Energy</td>
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<tr>
<td>Booker Trosper Unit</td>
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<td>Gramstorff Unit</td>
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<td>Farnsworth Unit</td>
<td>Chaparral Energy</td>
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<tr>
<td>Oyster Bayou</td>
<td>Denbury Resources</td>
<td>180</td>
<td>9000</td>
</tr>
<tr>
<td>Hastings, West</td>
<td>Denbury Resources</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CO₂ Flooding Operators Trends: Company Size over Time

- **Majors**
- **Large Independents**
- **Medium Independents**
- **Small Independents**

![Bar chart showing the number of operated CO₂ floods over time for different company sizes.](chart.png)
CO₂ EOR Supply in 2013

Key
- Potential Natural CO₂ Source
- Natural CO₂ Source
- NG Processing Source
- Conversion Source
- CO₂ Pipeline
- --- CO₂ Pipeline planned

- 360 MMcfpd
- 1700 MMcfpd
- ~150 MMcfpd
- ~50 MMcfpd
- ~15 MMcfpd
- 1600
- 150
- 1000 MMcfpd

Texas EOR Supply Numbers

The Permian Basin CO₂ EOR Infrastructure
PERMIAN BASIN
DAILY AVERAGE ANNUAL CO₂ PURCHASED - MCFPD

Source field decline issues
CO₂ EOR PURCHASES
ALL OF TEXAS

PERMIAN BASIN (TX) GULF COAST TX + PANHANDLE TX
DAILY AVERAGE ANNUAL CO₂ PURCHASED - McfPD

Daily Ave. Annual CO₂ Purchased in McfPD

YEAR

1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013

Melzer Consulting
Gulf Coast Supply

**Additional CO₂ Potential**
- Probable & Possible Reserves: ~3 TCF
- Improved Recovery of Proved Reserves: ~0.8 TCF

**Gulf Coast CO₂ Demand**

**JACKSON DOME**
- Risked Drilling Program
- Proved Reserves ~6.1 TCF
- Estimated as of 9/30/2012

*Note: Forecast based on internal management estimates. Actual results may vary.*
A Closer Look at CO₂ EOR Technology
CO₂ EOR Toolbag

Categories of Very Successful CO₂ Floods

• Geometry Category
  – Horizontal Miscible Floods (w/ Vertical Wells)
  – Vertical Miscible (Gravity Assisted) Floods
  – Vertical Immiscible (Gravity Assisted Floods)

• Lithology Category
  – Dolomites
  – Sandstones
  – Limestones

• Oil Type Category
  – Light Oils (Gravity > 25° API)
CO₂ EOR Toolbag

Categories of Moderately Successful CO₂ Floods

• Geometry Category
  – Horizontal Flooding of Immiscible Reservoirs

• Oil Type Category
  – Medium Gravity Oils

• Lithologies
  – Tripolites
  – Marls

• Secondary (Depressured Reservoir) CO₂ Floods
CO₂ EOR Toolbag
Categories of “Challenged” CO₂ Floods

• Geometry Category
  – Dipping Reservoirs – Miscible or Immiscible
  – Horizontal Injection Wells

• Age
  – “Pre-law” Wells

• Lithologies
  – Fractured
  – Compartmentalized (Vert or Hor)
CO₂ EOR Toolbag
Categories of “Emerging Technology” CO₂ Floods

- Residual Oil Zones
- Medium Gravity Oils
- Beating the Conformance Issues
  - Fractured Reservoirs
  - Highly Variable Permeability Sections in Reservoirs

Will also be covered in the next talk:
Dr. Trentham
Residual Oil Zones (ROZs)

• Industry Has Very Successfully CO$_2$ Flooded Mature Waterfloods
• Mother Nature Can Waterflood Also
• Can We Successful CO$_2$ Flood MNWs?
Mother Nature Can Waterflood Too!!
A Multiple Stage Tectonics Framework

1) Deposition

2) First Stage Tectonics: Basin Subsidence, Hydrocarbon Generation and Migration to a Trap

3) Second Stage Tectonics (Moving Oil Around):
   I  – Basinal Tilt,
   II – Breached Seal,
   III – Uplift and Lateral Sweep
The Science of Residual Oil Zones
Original Oil Accumulation Under Static Aquifer Conditions (A Hypothetical Example)
Original Accumulation Subject to a Westward Regional Tilt & Forming a ROZ

TYPE 1 ROZ
Original Accumulation with a Breached then Repaired Seal & Forming a ROZ

**TYPE 2 ROZ**
Change in Hydrodynamic Conditions, Sweep of the Lower Oil Column, Oil/water Contact Tilt, and Development Of The Residual Oil Zone

TYPE 3 ROZ

Note: Tilted Oil / Water Contact
Dr. Trentham’s Talk (Next) Will Continue this ROZ Subject
KEY TEXAS CO$_2$ EOR EVENTS

ROZ Exploitation

1992: Shell Initiates Commingled MPZ & Transition Zone Sweet Spot Flood at Denver Unit (DU) to 150 feet below OWC

1997: Altura Expands Transition Zone Project at DU to Phase I Area

1997: Hess Initiates Commingled MPZ & ROZ pilot at Seminole San Andres Unit (SSAU)

2005: Hess Initiates Dedicated ROZ pilot at SSAU


2008: Hess Begins Field-wide Deployment of ROZ Project at SSAU

2008: ARI et al Publish DOE Report on the ROZ Resource Base

2009: UTPB and ROZ Team, Funded by the Research Partnership to Secure Energy for America, Working to Better Explain the Origins and Distributions of ROZs in the Permian Basin
Concluding Thoughts and Observations

1. **CO₂ EOR has emerged as the Fastest Growing EOR Method and this is without Consideration for Value in CO₂ Storage** – 127 U.S. Projects Currently Making 350,000 bopd

2. **Residual Oil Zones are Emerging as Viable CO₂ EOR Opportunities in the Permian Basin.** Twelve Active Projects Underway Making >11,000 bopd.

3. **Growth in CO₂ EOR is Limited by Supplies of Available and Affordable CO₂.** Current Supplies (3.1 bcfpd {65 million tons per year} are 75% Pure Natural and 25% Industrial by-product)

4. **ROZ Opportunities Need to be Evaluated in Other Regions/Basins.** Is the Permian Basin Really Unique?

5. **Convergence of Storage Objectives Can Change the Pace of Deployment of CO₂ EOR in Dramatic Fashion**
Questions?
A Final Set of Thoughts on CO₂ EOR Technology
Renewed Growth of PB Production and New Evolving Estimates of OOIP

Cum Oil Production and Estimate of Original Oil in Place in the Permian Basin

- Estimated PB OOIP (BBbls)
- Cum Oil in BBbls

Year

Are We Comfortable with This?

Either as an Industry or as the State of Tx

Permian Basin Recovery Factors Vs. Time*

* Note: PB OOIP is increasing over time